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CONCENTRATIONS OF SELENIUM, MERCURY, AND LEAD IN BLOOD OF EMPEROR GEESE IN WESTERN ALASKA

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Abstract—We found up to 10 ppm wet weight of selenium in blood samples collected from emperor geese (*Chen canagica*) on their breeding grounds on the Yukon–Kuskokwim Delta in western Alaska, USA. Incubating adult females captured in late May through mid-June 1997 had significantly higher concentrations of selenium in their blood (mean = 5.60 ppm) than adult females captured during wing molt in late July 1996 (mean = 2.78 ppm). Females that nested early or were in good body condition had higher concentrations of selenium in their blood than did other nesting females. Blood samples from 4 of 29 goslings had detectable levels of selenium (mean = 0.14 ppm). Our findings suggest that emperor geese are exposed to more selenium in the marine environment of their wintering and staging areas on the Alaska Peninsula than on the breeding grounds. The highest concentration of mercury found in the blood of emperor geese was 0.24 ppm. One bird had a blood lead concentration of 0.67 ppm, but 82% had no detectable lead in their blood, suggesting that lead exposure from the ingestion of lead shot poses little threat for emperor geese in western Alaska, contrary to findings reported for sympatric spectacled eiders (*Somateria fischeri*).

Keywords—Emperor goose Lead Mercury Selenium

INTRODUCTION

The emperor goose (*Chen canagica*) is an arctic species that inhabits the Bering Sea coasts of western Alaska (USA) and northeastern Russia. Most emperor geese breed on the Yukon–Kuskokwim Delta (YKD) in western Alaska, use the northern side of the Alaska Peninsula as a spring and autumn staging area, and winter on the southern side of the Alaska Peninsula and the Aleutian Islands [1,2]. Alaska's emperor goose population has declined by about 50% since the mid-1960s and, although subsistence hunting has been identified as one probable factor, other potential contributors to the decline are not well understood [2].

Lead poisoning, as a result of the ingestion of spent lead shot, has recently been diagnosed in spectacled eiders (*Somateria fischeri*) and common eiders (*Somateria mollissima*) on the YKD [3]. Up to 35% of the blood samples collected from eiders and other diving ducks at this location have exhibited elevated concentrations of lead [4]. High concentrations of selenium also have been found in tissues of birds from interior and western Alaska. Mean selenium concentrations of 54 ppm and up to 77 ppm (both on dry weight basis) were reported in livers of white-winged scoters (*Melanitta fusca*) on Yukon Flats National Wildlife Refuge and spectacled eiders from St. Lawrence Island, respectively [5]. Feather samples from incubating spectacled eider hens on the YKD had selenium concentrations of 42 to 64 ppm dry weight [6]. Exposure of birds to selenium may lead to developmental abnormalities and adverse reproductive effects, and mortality of adult and juvenile mallards (*Anas platyrhynchos*) may occur when selenium concentrations in the liver reach 20 ppm wet weight [7], or about 66 ppm dry weight.

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The occurrence of lead poisoning and selenium exposure in other Alaskan birds, some of which breed in the same geographical area as emperor geese, led us to test blood samples from emperor geese for evidence of exposure to those trace elements. Because of the potential interactive effects between selenium and mercury [8], we analyzed a subset of samples for mercury and evaluated its correlation with selenium.

MATERIALS AND METHODS

Blood sample collection

In late July 1996, we captured emperor geese on their breeding grounds near the Manokinak (61°10′N, 165°10′W) and Kashunuk (61°20′N, 165°30′W) rivers, on the YKD in western Alaska. Flightless adults (99) and goslings (136) were herded into corrals and sexed by cloacal examination. In late May and early June 1997, we trapped 50 incubating adult females on their nests with bow net traps at the Manokinak site and measured culmen, total tarsus, and flat wing [9] of 37 of these birds to the nearest 0.1 mm. Egg hatching dates were estimated by floating eggs in water [10]. All geese were weighed to the nearest 25 g, and blood was collected by jugular venipuncture into heparinized glass tubes. Two of the incubating females were captured and bled twice at an interval of 15 d.

Trace element analyses

In 1996, our primary objective was to study lead exposure in emperor geese and all 235 blood samples collected that year were analyzed for lead by graphite furnace atomic absorption spectrophotometry (AAS) at the National Wildlife Health Center (NWHC), Madison, Wisconsin, USA [11]. For our initial evaluation of selenium concentrations in goose blood, we analyzed a subset of the 1996 samples, including blood from 45 (25 males and 20 females) adults and 29 (14 males and 15 females) goslings. We determined selenium concentrations in

the blood of each of the 50 adult females captured in 1997, a sample size similar to the number of blood samples from adults that were analyzed in 1996. From the 95 adult blood samples analyzed for selenium, a subset of 48 (18 males and 18 females in 1996 and 12 females in 1997) was analyzed for mercury. Selenium and mercury analyses were done by graphite furnace AAS and cold vapor reduction AAS, respectively [12–14], at Hazleton Environmental Services, Madison, WI, USA (36 of the adult samples from 1996) and En Chem, Madison, WI, USA (all others). Lower limits of detection were 0.20 ppm (Hazleton) and 0.08 ppm (En Chem) for selenium, 0.04 ppm for mercury (Hazleton and En Chem), and 0.02 ppm for lead (NWHC). Recoveries from spiked samples were 103 and 102% (Hazleton and En Chem, respectively) for selenium, 124 and 103% (Hazleton and En Chem, respectively) for mercury, and 94% (NWHC) for lead. All results are given in ppm wet weight, uncorrected for percent recoveries.

Statistical analyses

We tested for sex and location differences in selenium concentrations of blood samples collected from adults in 1996, using log-transformed data in a two-factor ANOVA [15]. A Wilcoxon rank sum test [16] was used to compare blood selenium concentrations of adult females captured during wing molt in 1996 with those of adult females trapped during incubation in 1997. For the computation of Spearman's rank correlation coefficient [16] between selenium and mercury, we assigned a mercury concentration (0.02 ppm) equal to one half of the lower limit of detection to the blood samples in which we found no mercury residues (n = 10). Because selenium was detected in only 14% of the blood samples from goslings, those data were omitted from statistical evaluations.

We examined variation in blood selenium concentrations with respect to date of blood collection, timing of nesting, and an index of body condition for the 37 incubating females for which we obtained all three morphologic measurements. As a preliminary step in this analysis, we calculated a size-corrected mass estimate as an index of body condition. We used a principal components analysis [17] to combine culmen, tarsus, and wing measurements into a single factor (the first principal component) representing body size. The first principal component accounted for 52% of the variation in the morphologic data. We then conducted a two-factor multiple regression [15] with both body size (the principal component score) and days to hatch as independent variables, and body mass as the dependent variable. This regression was significant (r^2 = 0.42, $p < 0.001$), with both days to hatch ($p < 0.001$) and body size ($p < 0.001$) influencing body mass. We then used the residuals from this analysis as indices of relative body condition. We used these indices, timing of nesting, and sampling dates as independent variables in a multiple regression model [15] to correlate with the blood selenium concentration. A fourth variable, timing of nesting raised to the second power, was included in the regression to allow modeling of temporal changes in selenium concentrations that were curvilinear rather than simply linear. From these four independent variables, we constructed 16 different regression models, each having an intercept and zero to four variables. The model with the lowest value for the Akaike Information Criterion (AIC) [18,19] was selected as the model that best fit our data. The AIC represents a balance between getting good fit of the model to the data (achieved with more variables) and obtaining precise parameter estimates for the included variables (achieved with fewer variables).

Table 1. Selenium concentrations (ppm wet weight) in the blood of adult emperor geese (*Chen canagica*) captured in western Alaska (USA) during incubation (late May to mid-June 1997) and wing molt (late July 1996)

	Mean (SE)	Range	n
Incubation			
Females	5.60[a] (0.04)	0.34–10.0	50
Wing molt			
Females	2.78 (0.41)	0.17–8.65	20
Males	3.46 (0.39)	0.25–6.93	25

[a] Significantly greater than mean of females at wing molt ($p < 0.001$).

RESULTS

Selenium

Selenium was detected in all blood samples from adult emperor geese that were tested (n = 95). The selenium concentration in the blood of adult females sampled during incubation (mean = 5.60 ppm) in 1997 was significantly greater than in adult females captured during wing molt (mean = 2.78 ppm) in 1996 (Table 1). The highest selenium concentration was 10.0 ppm in the blood of an incubating female. The best multiple regression model for the adult female data correlated selenium concentrations in the blood with body condition and timing of nesting (Table 2). Adult females in good body condition and those nesting earlier had higher blood selenium concentrations than did those in poorer condition or that nested later (Fig. 1). Sampling date was not related to the selenium concentration in the blood of incubating females (Table 2). The AIC value (Table 2) and probability values for the chosen model (Fig. 1) were similar to those from an analysis that excluded the two latest nesting females (n = 35).

The two adult females that were bled twice had initial selenium concentrations of 9.10 and 1.10 ppm and 15 d later their blood selenium concentrations were 7.80 and 1.20 ppm,

Table 2. Akaike information criterion (AIC) values and coefficients of determination (r^2) for multiple regression models relating body condition (BC), timing of nesting (TN), timing of nesting raised to the second power (TN^2), and sampling date (SD) to the concentration of selenium in the blood of adult female emperor geese (n = 37) captured during nesting in western Alaska, 1997. The best model (lowest AIC) is listed first

Variables in model	AIC	r^2
BC, TN^2	60.5	0.382
BC, TN	61.3	0.368
BC, TN, TN^2	62.4	0.383
BC, TN^2, SD	62.5	0.382
BC, TN, SD	63.1	0.371
BC, TN, TN^2, SD	64.4	0.383
TN^2	64.4	0.273
TN	64.8	0.267
TN^2, TN	66.4	0.273
TN^2, SD	66.4	0.273
TN, SD	66.8	0.267
TN^2, TN, SD	68.4	0.273
BC	72.2	0.103
BC, SD	73.1	0.130
None	73.3	0.000
SD	75.2	0.027

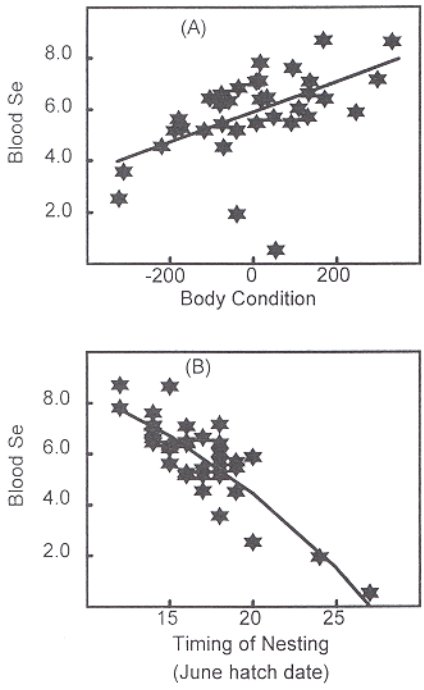

Fig. 1. Correlations ($r^2 = 0.382$, $n = 37$) of selenium concentrations in the blood (ppm wet weight) of emperor geese with (**A**) body condition (deviation in mass [g] from expected for given body size) (slope = 0.006, $p = 0.020$) and (**B**) timing of nesting raised to the second power (slope = −0.013, $p < 0.001$). Plotted lines are for estimated selenium concentrations.

respectively. Selenium was detected in the blood of 4 of 29 goslings, at concentrations of 0.11 to 0.18 ppm (mean = 0.14 ppm). The concentration of selenium in blood collected from adult emperor geese during wing molt did not differ significantly by sex or location ($p > 0.05$).

Mercury and lead

Mercury was detected in the blood of 79% of the 48 birds tested. The mean ± SE mercury concentration was 0.05 ± 0.01 ppm ($n = 38$), and the highest concentration was 0.24 ppm in an adult female captured during wing molt. Selenium and mercury concentrations were not correlated ($r^2 = 0.134$, $p = 0.363$, $n = 48$). Lead was detected in 18% of the 235 blood samples analyzed (mean ± SE = 0.04 ± 0.02; $n = 42$). The highest blood lead concentration was 0.67 ppm in an adult female during wing molt.

DISCUSSION

Comparison with experimental studies

The maximum selenium concentration (10 ppm) that we found in the blood of adult emperor geese was nearly as high as concentrations associated with deaths of experimental mallards receiving dietary selenium. When mallards that were fed selenium began to die, mean selenium concentrations in blood of survivors were 12 ppm in one study [20] and 5 to 14 ppm in another [21]. In a third experiment, selenium concentrations reached 16 ppm wet weight in the blood of mallards before they died or were euthanized after developing clinical signs or losing at least 30% of their body weight [22]. Selenium concentrations in the blood of control birds in these studies were about 0.4 ppm or less.

Selenium in blood of marine birds

Emperor geese spend much of their life cycle in coastal marine and brackish environments. Higher concentrations of selenium in tissues, primarily liver, have been found in marine birds than in freshwater birds [23,24], but few comparative data on selenium levels in the blood of wild marine birds are available. Sooty terns (*Sterna fuscata*), sampled in an area described by the authors as unlikely to be contaminated with industrial wastes, had mean selenium concentrations in their blood of 8.76 ppm wet weight [25]. Selenium concentrations of 21 ppm dry weight and 335 μg/L were reported in the red blood cells and plasma, respectively, of Eurasian oystercatchers (*Haematopus ostralegus*) from the Dutch Wadden Sea coast [26]. Assuming a moisture content of 70% for red blood cells, 21 ppm dry weight in red cells is the equivalent of about 6.3 ppm wet weight. Adding the 335 μg/L in plasma yields an estimated total of 3.3 ppm wet weight of whole blood (if hematocrit is 50%), somewhat lower than the mean of 5.60 ppm that we found in incubating emperor goose females. Embryotoxicity was not observed in the Eurasian oystercatchers and selenium concentrations in their eggs were within normal background concentrations [26]. Selenium concentrations in the red blood cells of marine-feeding Eurasian oystercatchers were about 3.5 times higher than in inland-feeding birds [26].

Exposure of emperor geese to selenium

We hypothesize that emperor geese are exposed to higher levels of selenium on their wintering and staging areas than on their breeding grounds. We base this hypothesis upon the fact that the mean concentration of selenium in the blood of incubating females during late May and early June 1997 was about twice as high as the mean for molting adult females in late July 1996, and that low levels of selenium were found in the blood of goslings. This agrees with other studies reporting that higher levels of selenium occur in birds of the same species feeding in marine areas compared with freshwater environments [26], and that selenium levels decline after birds leave the marine environment [27]. Although selenium is incorporated into feathers [28], it is unlikely that excretion of selenium into growing feathers accounted for the lower mean concentration of selenium in the blood of molting versus incubating emperor geese. The molting geese that we captured had lost only their primary feathers and the newly growing primaries were very small.

If high residues of selenium are passed to eggs, adverse reproductive effects may occur [7]. However, field observations did not reveal any conspicuous evidence of reproductive problems in this population of emperor geese. Five of the 50 females sampled in 1997 failed to produce young, but this was the result of predation and selenium concentrations in the blood of those birds were not higher than in the other 45 birds. Nest success (>80%) and gosling survival (mean = 50%) in this population during 1993 through 1996 was as high or higher in comparison with other populations (J.A. Schmutz, unpublished data). When selenium was removed from the diet of mallards, the first eggs that were laid contained high selenium concentrations, but concentrations in subsequent eggs declined quickly [29]. Results of stable isotope analyses indicate that the components of emperor goose eggs come primarily from food acquired on the breeding grounds [30], where we believe selenium exposure is low. Therefore, there may be little dietary contribution of selenium to most eggs in a clutch if emperor geese move from a high-selenium diet on wintering and staging

areas to a low-selenium diet on the breeding grounds. However, as eggs are formed we would expect selenium to be transferred to them from the circulating blood. Because selenium concentrations in blood of females were still high after the eggs were laid, eggs should be analyzed to better evaluate the potential effects of selenium on emperor geese.

Selenium, body condition, and timing of nesting

We found a positive relationship between blood selenium concentrations and body condition of incubating female emperor geese and a negative relationship between blood selenium and timing of nesting (Fig. 1). One explanation for these findings is that waterfowl arriving in good body condition may start nesting sooner than those arriving in poorer condition [31,32]. If selenium exposure on the wintering and staging areas is greater than on the breeding grounds, then birds that are in good body condition and consequently nest sooner after they arrive may have higher levels of selenium in their blood because they were more recently exposed. Using similar reasoning, birds arriving in poorer condition may feed before nest initiation for a longer period of time on the YKD, where foods may contain less selenium.

Decline of selenium in blood

The concentration of selenium in the blood of one of the geese from which we collected two sequential samples declined by 14% over a period of 15 d, whereas the concentration in the blood of the other bird increased by 9% during the same length of time. With sequential sampling results from just two birds, we can only speculate that the half-time for selenium in the blood of emperor geese is greater than 10 d, as reported in mallards [20], and that a low level of selenium exposure may occur on the breeding grounds, as evidenced by the presence of selenium in blood of some of the goslings. A low level of exposure of geese to selenium while on the YKD is further suggested by the mean of 2.78 ppm selenium found in the blood of adult females in late July during wing molt. Extension of the regression between blood selenium concentrations and timing of nesting (Fig. 1B) suggests that selenium in the blood of adult females at the time of wing molt would be nearly undetectable if no exposure occurred on the YKD.

Mercury and selenium

Although mercury and selenium concentrations in tissues of marine mammals are usually correlated, the interrelationships between mercury and selenium in marine birds are often highly variable [23]. Our results fit this pattern, in that we found low concentrations of mercury in the blood of emperor geese and no correlation between selenium and mercury. However, these findings are in contrast with two other studies of marine birds [25,33], where the levels of mercury that accompanied blood selenium concentrations were higher than those in emperor geese.

Lead

In contrast to results reported for sympatric spectacled eiders and other diving ducks [3,4], we found little evidence of lead exposure in emperor geese. These contrasting results likely reflect the differences in feeding ecology between the two species. Although spectacled eiders may ingest lead shot while feeding in small pools in tundra wetlands [4,34], emperor geese usually graze on vegetation above the soil surface and thus would rarely ingest spent lead shot. Although emperor geese may grub below the soil surface for a short time in early spring, before regrowth of vegetation, this probably represents their only opportunity for ingestion of lead shot on the YKD.

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